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Further evidence of validity of the Gait Deviation Index

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ABSTRACT

In this paper, the relationship of the Gait Deviation Index (GDI) to gross motor function and its ability to distinguish between different Gross Motor Function Classification System (GMFCS) levels was determined. A representative sample of 184 ambulant children with CP in GMFCS levels I ($n = 57$), II ($n = 91$), III ($n = 22$) and IV ($n = 14$) were recruited as part of a population-based study. Representative gait cycles were selected following a 3D gait analysis and gross motor function was assessed using the Gross Motor Function Measure (GMFM). GDI scores were calculated in Matlab. Valid 3D kinematic data were obtained for 173 participants and both kinematic and GMFM data were obtained for 150 participants. A substantial relationship between mean GDI and GMFM-66 scores was demonstrated ($r = 0.70$; $p < 0.001$) with significant differences in mean GDI scores between GMFCS levels ($p < 0.001$) indicating increasing levels of gait deviation in subjects less functionally able. The relationship between the GDI, GMFM and GMFCS in a representative sample of ambulators, lends further weight to the validity of the GDI scoring system. Furthermore it suggests that the subtleties of gait may not be wholly accounted for by gross motor function evaluation alone. Gait specific tools such as the GDI more likely capture both the functional and aesthetic components of walking.

1. Introduction

Due to the complexity and volume of data generated by three-dimensional gait analysis, categorisation of gait patterns in individuals with cerebral palsy (CP) has been the focus of numerous investigations. Such techniques seek to determine the extent of pathology and in many instances, assess the effectiveness of a given intervention. Primarily, classification techniques can be divided into two groups: qualitative and quantitative. The qualitative approach depends on the expertise of the clinician who attempts to categorise patients into pre-defined, distinguishable patterns. Examples of this type of approach have been documented in children with hemiplegia [1,2] and diplegia [3]. This type of approach is often useful in determining etiology and in some instances, can assist with formulating treatment plans [3]. Alternatively, quantitative methods mathematically analyse gait pattern deviation from a non-impaired sample and, though more objective, may be less user friendly in the clinical environment. This latter approach may be more useful in determining overall change in gait pattern and therefore be more useful as an evaluative tool in intervention studies with large cohorts of subjects.

The quantitative approach has employed various techniques such as cluster analysis [4], neural networks [5] and fuzzy logic [6]. However it was the development of the Gillette Gait Index (GGI), often referred to as the normalcy index [7], that was most embraced in the clinical literature. This latter tool uses principal component analysis to identify how 16 selected gait variables in a person with pathological gait vary from those of a typically developed (TD) control group; differences are presented as a single value. The authors suggest that pre- and post-intervention GGI values could be used to determine any change in gait as a result of an intervention. More recently the original authors of the GGI have highlighted a number of its limitations [8]; these include the choice of the component parameters and the interdependence between the GGI and control data used. As a result of these limitations, a new quantitative measure – the Gait Deviation Index (GDI) – has recently been proposed [8]. Utilising pattern recognition, the GDI compares nine kinematic variables of a subject's gait against those of a control group; this requires kinematics from the pelvis and hip in all three planes, the knee and ankle in the sagittal plane and foot progression. Each lower limb is considered independently. This method of comparison involves compiling a large dataset composed of control and clinically impaired kinematic data, the aim being to reflect the extent of gait variation possible. Singular value decomposition is then employed to decompose the dataset whereby the range of

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variation in gait can be extracted as a series of vectors designated 'gait features'. The first gait feature corresponds to the largest variance in the data with each subsequent gait feature representing the increasingly smaller, remaining variance. Schwartz and Rozumalski, using kinematics from a sample of 6702 limbs, illustrated that 98% of gait could be described using 15 of the 459 computed gait features [8]. These 15 gait features, applied to a control group, define an averaged, non-pathological gait. Subsequently, the absolute distance between a subject exhibiting gait pathology and the control group is calculated and from this value the extent of pathology can be determined. A GDI score can then be calculated; a score of 100 and above denotes non-pathological gait, standard deviation bands are scaled to 10-point intervals below 100 [8].

In order to determine the face validity of any new index it is necessary to compare it with existing standards. Validation of the GDI has been carried out by comparison with the GGI, Gillette Functional Assessment Questionnaire (FAQ) and traditional topographical classification (e.g. hemiplegia, diplegia) [8]. However, in the area of CP, the Gross Motor Function Measure (GMFM) is considered the gold standard measure of functional ability. Whilst it is not specifically tailored to lower limb function alone, the GMFM still provides an excellent description of overall locomotor ability. In addition, the Gross Motor Function Classification System (GMFCS) is now regarded as a gold standard in the functional classification of children with CP [9]. Thus, in an effort to further validate the GDI, its relationship with the GMFM and GMFCS has been explored in an ambulant sample of children with CP.

2. Methods

Ethical approval for this study was granted from the local Research Ethics Committee.

2.1. Participants

A representative sample of 184 ambulant children diagnosed with CP classified in GMFCS levels I ($n = 57$), II ($n = 91$), III ($n = 22$) and IV ($n = 14$) were recruited to a longitudinal study of locomotor function in a geographical defined region (112 male; 94 with unilateral spastic CP (USCP), 84 with bilateral spastic CP (BSCP) and 6 with other bilateral forms; age range 4–17 yrs; mean age 10.8 ± 3.6 yrs; mean height 1.4 ± 0.2 m; mean weight 38.7 ± 16.9 kg). A comprehensive account of the recruitment strategy and representativeness of the sample is documented elsewhere [10]. Additionally, previously collected data from a group of 48 typically developed children (22 male; age range 4–17 yrs; mean age 9.85 ± 3.5 yrs mean height 1.4 ± 0.2 m; mean weight 36.5 ± 14.9 kg) were used as a control group. All parents/guardians and children (where possible) signed informed consent.

2.2. Data collection and processing

An experienced physiotherapist assessed functional ability of the participants using the Gross Motor Function Measure (GMFM) [11]. All participants were tested barefoot and without aids. The same physiotherapist also classified each patient using the GMFCS.

Kinematic data were collected using a 6-camera Vicon 612 motion analysis system with Workstation software (Oxford Metrics, England). A full description of the capture system and data capture technique is detailed elsewhere [12]. Participants walked barefoot at a self-selected speed unaided but using assisting devices if required. A minimum of three trials of valid kinematic data was captured or, alternatively, three valid trials per limb.

2.3. Data processing

GMFM-66, GMFM-88 and dimension scores were calculated as recommended by the authors [11].

All available trials of kinematic data were exported from Workstation to a custom made application in Matlab (MathWorks, Natick, MA). This produced sagittal kinematic plots of the pelvis, hip, knee and ankle for each cycle. A Bioengineer and Physiotherapist experienced in gait analysis selected a representative gait cycle (RGC) bilaterally for each participant by selecting a plot which demonstrated consistency with the majority of other plots (on key kinematic gait variables). Where the choice was not unanimous, a second Physiotherapist assisted with the choice.

The GDI calculation method, as described by its authors [8], was replicated in Matlab. Initially GDI scores for our control group were obtained using the electronic addendum provided with the GDI paper, i.e. using the control data of Schwartz and Rozumalski [8]. Subsequent to this, GDI scores for our CP participants were calculated using our own control data. GDI scores were calculated bilaterally for all of the participants. Individual limb GDI and mean GDI scores (mGDI) were used in subsequent analyses.

2.4. Data analysis

Statistical analysis was performed using SPSS v.13 (SPSS Inc., Chicago, IL). The assumptions of normality were verified by using the Kolmogorov–Smirnov (K–S) test. Pearson's correlation coefficient was used to describe the relationship between mGDI and (i) GMFM-66 scores, (ii) GMFM-88 scores and (iii) GMFM dimensions A–E. An analysis of variance, with Duncan's post hoc test as appropriate, was used to determine significant differences in GDI scores between GMFCS levels.

3. Results

Valid 3D kinematic data were obtained for 173 participants whilst both sets of data (GDI and GMFM data) were obtained for 150 participants (95 male; age range 4–17 yrs; mean age 10.9 ± 3.6 yrs).

Fig. 1A and B illustrate the normal distribution of individual GDI scores for our control ($n = 96$ limbs) and CP group ($n = 346$ limbs), respectively. These were confirmed by K–S tests. The normative mean and standard deviation (Fig. 1A) was similar to that reported by Schwartz and Rozumalski [8]. The histograms illustrate the distribution of lower GDI scores in children with CP.

The scatterplot in Fig. 2 illustrates the significant relationship between mGDI and GMFM-66 scores: $r = 0.70$; $p < 0.001$. Further analysis showed this relationship to be slightly better than that recorded with GMFM-88 scores ($r = 0.67$ $p < 0.001$). The gait-centric aspects of the GMFM-88, represented by dimensions D and E, demonstrated a stronger relationship with mGDI scores ($r = 0.69$ and 0.70, respectively) than those concerned with activities such as lying, rolling and crawling, i.e. dimensions A–C ($r = 0.48$, 0.43 and 0.34, respectively). Mean GDI scores for the control group and by

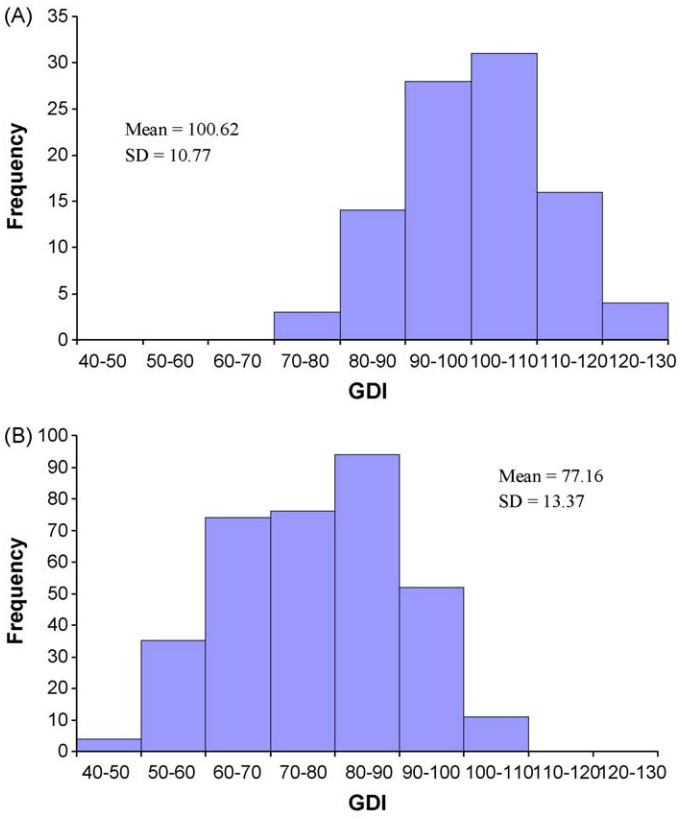

Fig. 1. (A and B) GDI distribution in control group ($n = 96$ limbs) and CP group ($n = 346$ limbs), respectively.

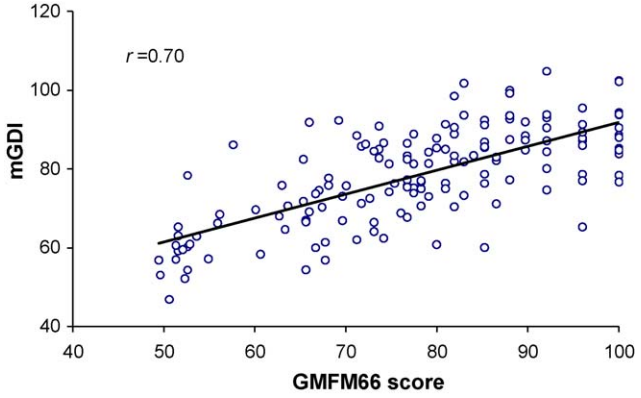

Fig. 2. Scatterplot of mean GDI scores (mGDI) plotted against GMFM-66 scores ($n = 150$).

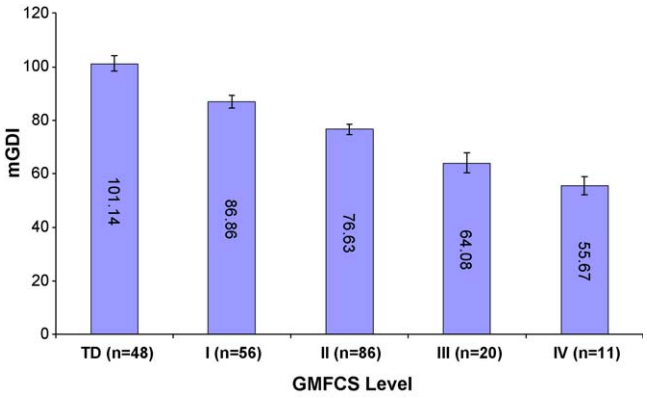

Fig. 3. Mean GDI scores (mGDI) with confidence intervals with 95% confidence intervals by GMFCS level ($n = 150$). Significant differences between groups ($p < 0.001$) and all adjacent levels ($p < 0.05$).

GMFCS level are illustrated in Fig. 3. Results showed significant differences between groups ($p < 0.001$) with increasing levels of gait deviation in subjects less functionally able. Post hoc tests revealed significant differences between all adjacent GMFCS levels.

4. Discussion

In an attempt to further validate the GDI, an investigation was carried out to determine its distribution within a representative population of children with ambulant CP, and to determine its relationship with function as measured by the GMFM and as classified by the GMFCS. Individual limb data for both the control and CP groups followed a normal distribution and a significant relationship with GMFM-66 scores was demonstrated. A similar relationship was evident for GMFM-88 scores; with dimensions D and E displaying the highest correlations. Significant differences in mGDI scores were also detected between all adjacent GMFCS levels.

The GMFM is a measure of overall physical function and, whilst it is possible to look at the dimensions that focus on lower limb ability, some consideration should be given to the nature of the activities scored. Dimension D assesses standing activities that do not specifically relate to locomotion whilst dimension E covers walking, running and jumping. Thus, it is likely that a large element of the variance not accounted for between mGDI and GMFM scores is due to both the specificity of the GDI and the scope of the GMFM. Furthermore, during the gait assessment children were allowed to use their assistive device if required; such assistance was not permitted during the GMFM assessment. A more comparative GMFM dataset would have allowed the use of an assistive device. The slightly lower correlation with GMFM-88 scores, as compared to GMFM-66 scores, is not surprising given that the latter is an interval level scale designed to reflect more clearly all levels of CP ability within a population and thus better able to discriminate motor function at extremes of the scale [11].

Mean GDI scores were used as an indicator of overall gait and this was considered necessary in light of the fact that the GMFM accounts for function in both lower limbs. In the case of children with unilateral involvement (USCP) or asymmetric bilateral involvement, using the affected/more affected limb score may not have reflected a subject's overall gait and inherent function. Thus the decision to average GDI's was considered. Interestingly, further analysis of our data by topographical classification showed no significant difference between the affected and unaffected limbs in children with USCP: Means and standard deviations of 81.1 ± 18.2 and 82.2 ± 17.8, respectively. This latter finding is perhaps not surprising as compensatory mechanisms adopted by children with hemiplegia, including increased hip and knee flexion of the non-involved limb, can be considerable. Furthermore, any deviations at the level of the pelvis are associated with equal deviation on the contralateral side. These results conflict with those of Schwartz and Rozumalski [8] who showed significant differences between the affected and unaffected limbs in children with USCP.

A limitation of the study was that the selection of each subject's RGC only included multiple gait cycles in the sagittal plane (pelvis, hip, knee and ankle). The chosen RGC, whilst indicative of gait in the sagittal plane, may not have reflected that of the five remaining aspects. While it is evident that sagittal plane kinematics have the greatest influence on gait, and hence would constitute the greatest variability, a more rigorous method of defining the RGC would have included all nine aspects of gait.

Calculating a GDI is, with the spreadsheet provided by the authors [8] (electronic addendum), a moderately easy process provided the subject and control group data is in the appropriate format. Vicon's Polygon (Version 2.1 – Build 109) was employed in this study to define the 459 datum; Polygon linearly interpolates the 51 points in each kinematic prior to exporting [13] and it is assumed that other gait capture system software would have similar functionality. Schwartz has confirmed that the 459 datum for each of the 6702 strides was extracted directly from a Vicon c3d and/or gcd file [14]. The interpolation method used by Vicon is undocumented but it is likely that the difference between data generated by linear and a more optimal method, such as cubic-spline interpolation, is small given the low frequency of gait kinematics.

Fifteen gait features are included in the GDI calculation spreadsheet, accounting for 98% of the variance in gait exhibited by 6702 limbs. Although the gait features are non-native, they account for the variability in gait of a large population of children and, as variance is the basis of the comparison between a subject and a control group, using the provided features should provide a high level of efficacy. Whilst access to such a large number of subjects is not available to all, calculation of gait features with comparable variance accounted for may require a much smaller sample. Indeed, the mean and standard deviation of the normative dataset in this study (Fig. 1A) are comparable to the normative values set as the default by Schwartz et al. of 100 ± 10 [8]. Further work should determine the sample size required to adequately represent the variance in normal gait.

The strength of the GDI is in illustrating the overall change in pathological gait as a result of intervention. Alternatively, whilst pre and post-intervention GDI scores may indicate the extent to which pathology has changed, they do not impart information on the cause or nature of the change. Clearly a positive change is favourable to the patient but, given the single-value format of a GDI, it alone should not be used to assess the effectiveness of an intervention. Multi-level

surgery presents a problem; identifying where, and to what extent, each surgical procedure has had an effect (positive or negative) is not apparent from the GDI. This lack of detail has motivated the creation of the Movement Analysis Profile (MAP) and Gait Profile Score (GPS) [15] and is likely to prompt further efforts to quantify gait pathology. Therapists and surgeons may find the lack of a descriptive component in the GDI a sufficient enough limitation to choose an alternative, more easily implemented and more comprehensive descriptor of gait. Despite these perceived shortcomings, Schwartz and Rozumalski present a compelling treatment-planning scheme [8] whereby utilizing the terse nature of the GDI, patterns in the efficacy of treatment for various gait abnormalities could be identified. It should be noted that a large dataset is one of the enabling factors in a scheme of this kind.

As a method of quantifying the extent of gait pathology and indicating functional ability, the usefulness of the GDI is further validated through the relationships displayed in this study. Conversely, it also confirms that gait pattern is a fundamental component of motor ability in children with CP, lending further weight to validity of the GMFCS. Future research needs to determine its stability over time and establish its value as an evaluative tool in intervention type studies.

Conflict of interest statement

No conflict of interest has been declared by any of the authors.

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